Using climate data to map the potential distribution of *Culicoides imicola* (Diptera: Ceratopogonidae) in Europe

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Summary
Culicoides imicola, a vector of bluetongue virus and African horse sickness virus, is principally Afro-Asian in distribution, but has recently been found in parts of Europe. A logistic regression model based on climate data (temperature, saturation deficit, rainfall and altitude) and the published distribution of *C. imicola* in Iberia was developed and then applied to other countries in Europe, to identify locations where *C. imicola* could become established. The model identified three temperature variables as significant determinants of the distribution of *C. imicola* in Iberia (minimum of the monthly minimum temperatures, maximum of the monthly maximum temperatures and number of months per year with a mean temperature $\geq 12.5°C$). The model indicated that under current conditions, the distribution of *C. imicola* in Spain, Greece and Italy could be extended and the vector could potentially invade parts of Albania, Yugoslavia, Bosnia and Croatia. To simulate the effect of global warming, temperature values in the model were increased by 2°C. Under these conditions, the potential spread of *C. imicola* in Europe would be even more extensive.

Keywords
African horse sickness – Arbovirus – Bluetongue – Climate change – Culicoides imicola – Global warming – Mapping – Model – Vector-borne diseases.

Introduction

The biting midge *Culicoides imicola* (Diptera: Ceratopogonidae) is found in sub-Saharan Africa (24), North Africa (3, 23, 51) and southern Asia (55). The species is also found in parts of Europe, including south-western Iberia (46) and the Greek islands of Lesbos (9), Rhodes (8), Chios, Kos, Leros and Samos (M. Patakakis, personal communication). In addition, the range of the insect in Europe appears to be expanding. In 1999, *C. imicola* was discovered for the first time in mainland Greece, in the prefectures of Thessaloniki, Khalkidhiki, Larisa and Magnisia (M. Patakakis, personal communication), while in 2000, the species was detected for the first time in Italy, in the regions of Sardinia, Sicily, Calabria and Tuscany (M. Goffredo, personal communication; P. Scaramozzino, personal communication) and in France, on the island of Corsica (39).

Culicoides imicola is a vector of several arboviruses of livestock, including bluetongue virus (BTV), which infects ruminants, and African horse sickness virus (AHSV), which infects equids.

The diseases caused by these viruses, bluetongue (BT) and African horse sickness (AHS), are of major international concern and are therefore classified as List A diseases by the Office International des Epizooties (OIE). Although BT and AHS are not endemic in Europe, epidemics occur periodically in the south (Table I). During the period from 1998 to 2000, BT has occurred in several countries in the Mediterranean Basin, resulting in the loss of over 100,000 sheep (32, 34, 35, 36, 37, 39, 40, 41, 42, 43). *Culicoides imicola* has been implicated as the principal vector species in the outbreaks of BT and AHS in Europe (28, 44), with the exception of the outbreaks of BT in Bulgaria and northern Greece (33), where *C. imicola* has not been found.

Areas in which *C. imicola* is found are potentially at risk of BT and AHS, but discoveries of *C. imicola* in Europe are usually only made following outbreaks of disease. A better approach would be to determine the distribution of *C. imicola* in Europe in advance of disease outbreaks, so that control measures (e.g. vaccination, use of insecticides and insect repellents,

Table I
Outbreaks of bluetongue and African horse sickness in Europe

Outbreak	Date	Reference(s)
Bluetongue		
Portugal and Spain	1956-1960	12
Lesbos	1979	52
Rhodes	1980	16
Greece (mainland Greece, Chios, Evia, Kos, Leros, Lesbos, Rhodes, Samos, Skiathos, Skopelos and Thassos)	1998-2000	32, 34, 36, 37, 38, 42
Bulgaria	1999	35
European Turkey	1999	35
Corsica	2000	39
Italy (mainland Italy, Sardinia and Sicily)	2000	40, 43
Majorca and Menorca	2000	41
African horse sickness		
Spain	1966	15
Spain and Portugal	1987-1990	48

housing of susceptible animals during periods of peak vector activity) can be targeted more effectively. This approach would be particularly valuable considering the present BT situation in the Mediterranean.

Climate is a major factor governing the distribution of *C. imicola* (29). For example, evidence suggests that the northern limit of *C. imicola* in Iberia may be determined by low temperature (5). Where temperatures are favourable, precipitation may influence distribution through an impact on the availability of breeding sites. *Culicoides imicola* breeds in wet, organically enriched soil or mud (10, 11, 22, 53, 54), and in Africa, tends to occur in regions with an annual rainfall of 300-700 mm (27), although other factors (e.g. irrigation and spillage from animal drinking troughs) may also be involved. Therefore, to establish the areas in which *C. imicola* could occur, a possible approach is to identify the most significant climatic determinants of the current distribution in Europe and from these, to derive 'expected' distributions for other parts of Europe. These 'expected' distributions could then be used to target field surveys to search for *C. imicola* in advance of disease outbreaks.

This study was therefore performed to identify the most important climatic factors influencing the distribution of *C. imicola*, using published data on the presence and absence of *C. imicola* in Iberia (46), together with climate data from this region (1). The derived climatic model can then be used to identify other areas of Europe with similar climates, presumed to be suitable for the occurrence of *C. imicola*. In addition, with a 2°C rise in the global mean temperature expected to occur during the next 100 years as a result of global climate change (20), the range of *C. imicola* in Europe could be extended even further (e.g. a 2°C increase in the mean annual temperature corresponds to a northward shift of approximately 200 km) (19). This increase in temperature can then be

incorporated into the model, to investigate how climate change may affect the distributional range of *C. imicola* in Europe.

Methods

Climate data for sites in Iberia were based on the average values for the period 1931-1960 (1). These values were used because the data for different countries are directly comparable. This contrasts with the information available for the more recent period, 1961-1990 (2), where, for example, temperature variables such as the minimum of the monthly minima and maximum of the monthly maxima are available for several countries, but not for Spain.

Thirty sites in Iberia occurred within regions for which information is available about the occurrence of *C. imicola* (46). *Culicoides imicola* was classed as present at sixteen sites and was absent from fourteen sites (Fig. 1).

Fig. 1
Sites included in the logistic regression analysis of the distribution of *Culicoides imicola* in Iberia
The presence or absence of *C. imicola* at the sites was determined from published data (46)

Climatic variables

Temperature variables for the thirty sites used in the analysis included the following:

– minimum of the monthly minima

– minimum of the monthly means

– mean of the monthly means

– maximum of the monthly means

– maximum of the monthly maxima

– number of months per year with a mean temperature ≥ 10.5°C

– number of months per year with a maximum temperature ≥ 12.5°C

– number of months per year with a mean temperature ≥ 12.5°C.

The number of months per year with a mean temperature ≥ 10.5°C was included as an indicator of whether immature development could occur at the sites. Thus, although the minimum temperature for development of *C. imicola* is not known, the developmental threshold temperature for a laboratory colony of *C. sonorensis* (formerly *C. variipennis sonorensis*) (18), a species from North America which breeds in similar habitats to *C. imicola*, is ≈ 10.5°C (56). The number of months per year with a maximum temperature ≥ 12.5°C was included because adult *C. imicola* can only survive the winter in areas where the average daily maximum temperature during the coldest month of the year (i.e. minimum of the monthly maximum temperatures) is ≥ 12.5°C (50). However, while adults may survive when the maximum temperature during the coldest month is ≥ 12.5°C, activity of these individuals will be limited. Consequently, the number of months per year with a mean temperature ≥ 12.5°C was also considered.

The annual daily mean saturation deficit, a measure of the drying power of air based on both air temperature and relative humidity, was also included for each site. This was determined by averaging the annual daily maximum and minimum saturation deficits. Making the assumption that maximum temperatures coincide with minimum relative humidities, and vice versa, the annual daily maximum saturation deficit was calculated from the annual average daily maximum temperature and the annual average daily minimum relative humidity, while the annual daily minimum saturation deficit was calculated from the annual average daily minimum temperature and the annual average daily maximum relative humidity.

The total annual rainfall and altitude for each site were also included in the analysis.

Analysis

Logistic regression, using the software 'Glim 3.77', was employed to determine which climatic variables were most important in distinguishing between sites where *C. imicola* is present and absent. The derived model was then used to calculate the probability of occurrence (values ranging from 0 to 1) of *C. imicola* at each of the thirty sites. *Culicoides imicola* was classed as present at sites with a probability of occurrence value of ≥ 0.5 and absent from sites with a value < 0.5. The predicted presence or absence of *C. imicola* at each site was compared with the published data (46) (Fig. 1), to assess the accuracy of the model. The model was then applied to additional sites in Iberia for which no information is available regarding the occurrence of *C. imicola*, and was also used to assess the suitability of other sites in southern Europe. Climate data from these sites required for the model predictions were obtained from published records (1). To simulate climate change, the temperature values were increased by 2°C and the model was then reapplied to the sites in Europe.

Results

Mean values for the climatic variables at the thirty sites in Iberia used to produce the logistic regression model are presented in Table II. Three climatic variables, namely: minimum of the monthly minimum temperatures, maximum of the monthly maximum temperatures and the number of months per year with a mean temperature ≥ 12.5°C, were significant in distinguishing between sites where *C. imicola* is present and absent (Table II).

The logistic regression model for Iberia, based on these variables is as follows:

$$y = 0.5460*a + 0.6020*b - 0.4243*c - 15.78,$$

where *a* is the minimum of the monthly minimum temperatures, *b* is the maximum of the monthly maximum temperatures, *c* is the number of months per year with a mean temperature ≥ 12.5°C and *y* is the logit transformation of the probability of occurrence of *C. imicola* (*p*) (Eq. 1). The probability of occurrence of *C. imicola* can then be calculated using Equation 2 (13).

Table II
Mean values (± standard error) for the climatic variables and results of the logistic regression analysis for the distribution of *Culicoides imicola* in Iberia

Climatic variable	Sites with *C. imicola* (*n* = 16)	Sites without *C. imicola* (*n* = 14)	X^2 (df = 1)
Altitude (m)	83.6 ± 18.7	56.4 ± 18.0	0.33
Temperature (°C)			
Minimum of the monthly minima	5.1 ± 0.7	4.8 ± 0.6	6.39[a]
Minimum of the monthly means	8.9 ± 0.6	8.7 ± 0.6	0.35
Mean of the monthly means	16.5 ± 0.5	15.5 ± 0.4	2.22
Maximum of the monthly means	25.0 ± 0.6	23.0 ± 0.7	0.44
Maximum of the monthly maxima	31.8 ± 0.8	28.3 ± 1.0	7.28[b]
No. months/year mean temperature ≥ 10.5°C	9.6 ± 0.5	9.4 ± 0.4	0.02
No. months/year maximum temperature ≥ 12.5°C	11.1 ± 0.3	11.1 ± 0.3	0.04
No. months/year mean temperature ≥ 12.5°C	8.5 ± 0.4	7.8 ± 0.3	4.34[a]
Saturation deficit (mbar)	7.2 ± 0.3	6.0 ± 0.4	0.44
Total annual rainfall (mm)	607.4 ± 46.4	635.5 ± 86.6	0.71

df: degrees of freedom
a) *P* < 0.05
b) *P* < 0.01

$$y = \ln\left(\frac{p}{1-p}\right) \qquad \text{(Eq. 1)}$$

$$p = \frac{1}{1+\frac{1}{e^y}} \qquad \text{(Eq. 2)}$$

The model correctly predicted the presence or absence of *C. imicola* at twenty-five of the thirty sites (83%) in Iberia. However, *C. imicola* was incorrectly predicted as present at three sites (10%) in eastern Spain (Granada, Almeria and Alicante) and incorrectly predicted as absent at two sites (7%) in Portugal (Braganca and Coimbra).

The suitability of sites in Europe for the occurrence of *C. imicola*, based on the model established for Iberia, is shown in Figure 2. In addition to southern Iberia, there is a high probability that *C. imicola* could occur in the Balearics, Sardinia, Sicily and parts of southern Italy. Parts of central Greece would also be favourable, although the probability of *C. imicola* occurring in areas of northern Greece or the Peloponnese is lower. The analysis also revealed a high probability that parts of the eastern Adriatic Sea coastline, ranging from Albania to Croatia, would be favourable for *C. imicola*.

A 2°C increase in temperature would extend the areas of Europe favourable for *C. imicola* (Fig. 3). For example, the likelihood of *C. imicola* occurring in sites on the east coast of Spain, the south coast of France and Corsica will greatly increase. The probability is also high that the majority of sites in southern Italy, extending into Tuscany and Liguria, will become suitable. The likelihood of *C. imicola* occurring in northern Greece will increase and more sites along the coastline of the eastern Adriatic Sea will have suitable climates for *C. imicola*. In addition, the suitability of sites in European Turkey and eastern Bulgaria will greatly increase. For example, at Edirne in Turkey (Fig. 3, labelled site A), the probability of occurrence of *C. imicola* increases from only 0.07 under current conditions to 0.45 after a 2°C increase in temperature.

Although annual rainfall was not significant in distinguishing between locations in which *C. imicola* is present and absent in Iberia (Table II), this may be an important determinant of the distribution of *C. imicola* in other parts of Europe. Annual rainfall is similar at sites where *C. imicola* is both present and absent in Iberia and is generally within the favourable range of 300 mm-700 mm per year, although *C. imicola* also occurs at some sites with an annual rainfall of 701 mm-1,000 mm (e.g. Braganca, Castelo Branco, Coimbra and Lisbon) (Fig. 4). *Culicoides imicola* pupae drown when breeding sites are flooded (31), and hence sites with an annual rainfall of > 1,000 mm are likely to be unsuitable (unless drainage of the soil is very rapid). Thus, while rainfall is not a limiting factor in Iberia, several sites along the coastline of the eastern Adriatic Sea, predicted by the model (on the basis of temperature) as suitable for the occurrence of *C. imicola*, may in fact be too wet (e.g. Mostar, Podgorica and Gjirokaster) (Fig. 4, labelled sites A-C). Furthermore, global mean precipitation is expected to increase as a result of temperature changes (20), which could result in additional sites becoming unsuitable for the occurrence of *C. imicola*.
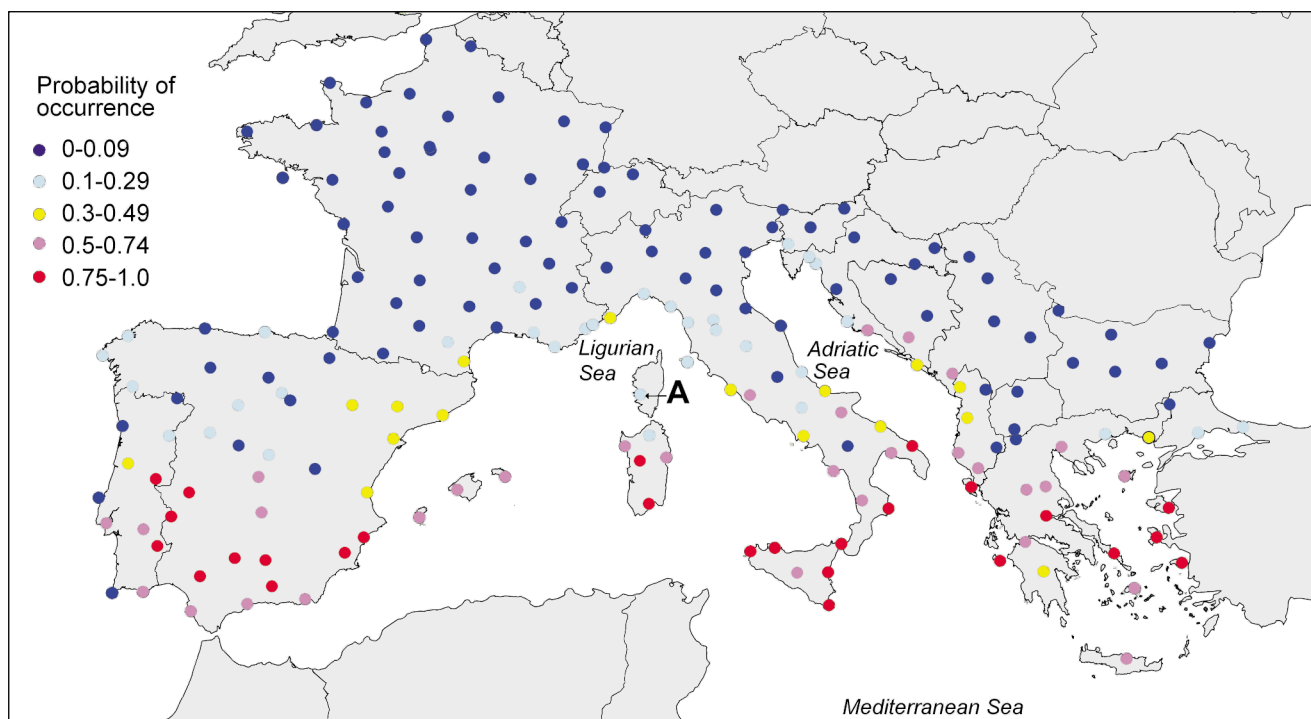

Fig. 2
Suitability of sites in Europe for the occurrence of *Culicoides imicola*, based on the logistic regression model established for Iberia
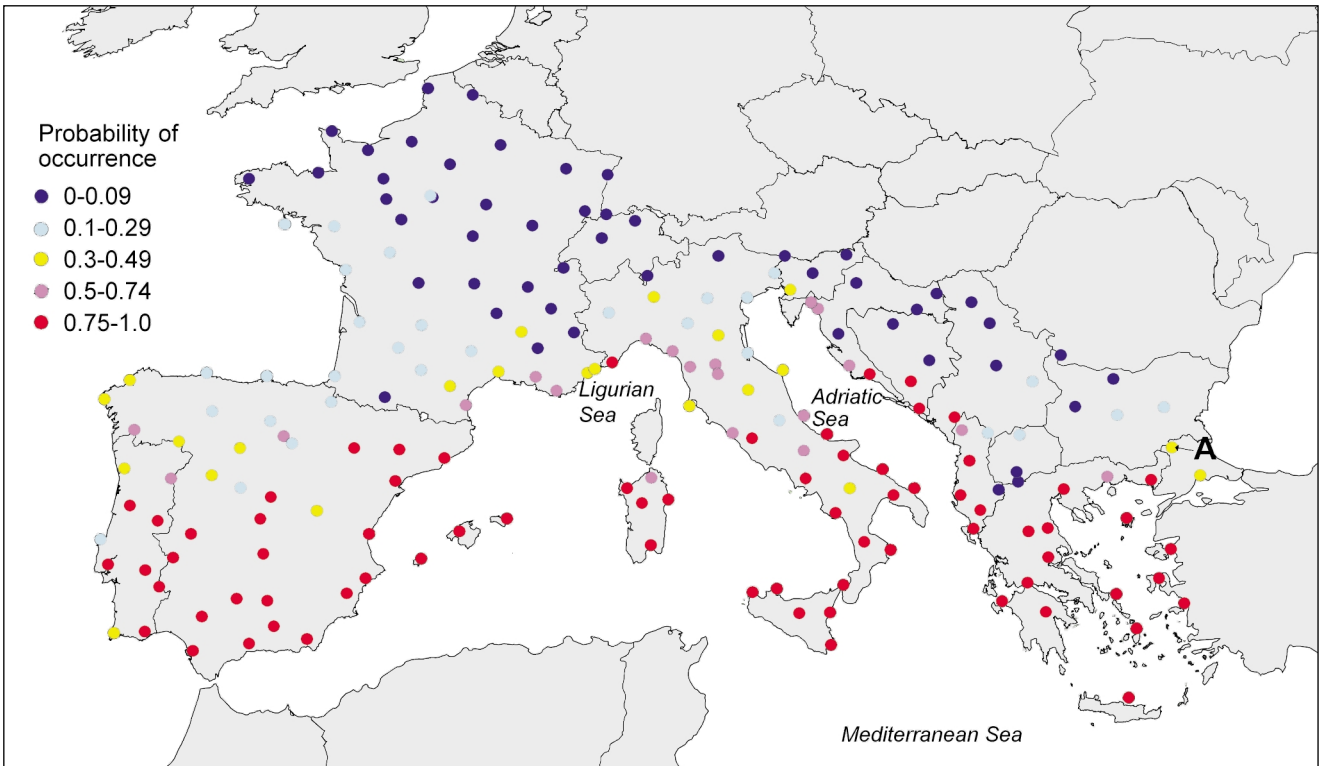Labelled site (A) is Ajaccio

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Fig. 3
Suitability of sites in Europe for the occurrence of *Culicoides imicola,* based on the logistic regression model established for Iberia with a 2°C increase in temperature
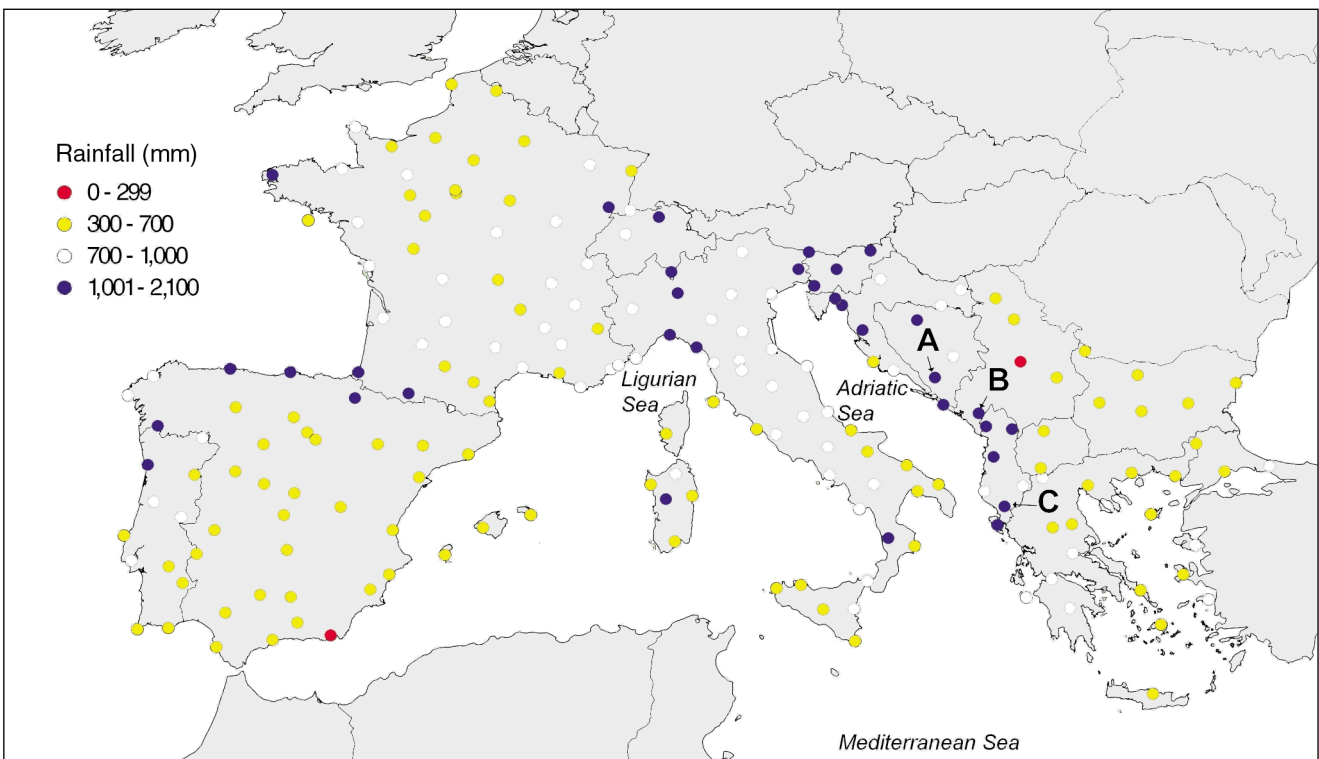Labelled site (A) is Edirne

Fig. 4
Total annual rainfall for sites in Europe
Labelled sites are Mostar (A), Podgorica (B) and Gjirokaster (C)

Discussion

The distribution of *C. imicola* in Iberia appears to be limited by temperature. The minimum of the monthly minimum temperatures, the maximum of the monthly maximum temperatures and the number of months per year with a mean temperature ≥ 12.5°C were significant determinants of the distribution of *C. imicola*. The model based on these temperature variables displayed a high degree of accuracy in predicting the occurrence of *C. imicola* in Iberia.

Although the analysis identified the major environmental constraints affecting the distribution of *C. imicola* in Iberia, the small percentage of sites for which presence or absence was incorrectly predicted, suggests that additional parameters may be involved. For example, factors such as wind speed (which affects activity and mortality of adult *C. imicola*) (4, 6, 53), soil type (which influences breeding site quality) (25, 26), presence of hosts, interactions with competitors and natural enemies (14), and species dispersal (which can allow populations to persist in sub-optimal conditions) (14) were not included in the analysis, but may be important determinants of distribution. In addition, the accuracy of the model may have been improved by incorporating satellite-derived climatic variables in the analysis, such as land surface temperature (a correlate of temperature on the surface of the earth) (45) and normalised difference vegetation index (a measure of photosynthetic activity strongly correlated with soil moisture) (17, 30). These variables have been used to model the distribution of *C. imicola* in South Africa (7).

However, the sites at which occurrence of *C. imicola* was apparently incorrectly predicted provide a useful insight into the possible future spread of *C. imicola*. Thus, the range of *C. imicola* could expand into south-eastern Spain (e.g. Granada, Almeria and Alicante). This region has previously been identified as suitable for the invasion of *C. imicola* (5, 47) and further, more intensive sampling in this area may reveal the presence of the species. However, in some areas of south-eastern Spain where temperatures appear suitable, the conditions may be less favourable for *C. imicola*, as other factors, such as rainfall may prove to be important (e.g. the annual rainfall in Almeria is < 300 mm).

The impact of temperature on distribution was not unexpected, as the northern limits of the global distribution of *C. imicola* are found in Iberia. The analysis indicates that the presence of *C. imicola* is favoured by relatively high summer temperatures (Table II), which will influence population growth rates, combined with mild winter temperatures (Table II), which will influence the overwintering success of immature and adult midges. In addition, the number of months per year with a mean temperature ≥ 12.5°C provides a further indicator of the likelihood of population growth and persistence at a site.

The application of the model based on Iberia to other countries of Europe has provided useful insight into identifying the locations in which *C. imicola* could occur. In Greece, not only does the model correctly predict that *C. imicola* could occur in some of the areas where it has already recently been found (e.g. Thessaloniki, Larisa, Chios, Lesbos and Samos), but occurrence is also predicted in areas further south in mainland Greece and on the islands of Andros, Corfu, Crete, Limnos, Naxos and Zakynthos. Further sampling in Greece may reveal that *C. imicola* is already present in some of these suitable areas. However, local topography may prevent *C. imicola* from easily invading some of these sites. For example, a potential route of introduction of *C. imicola* to Corfu and Zakynthos requires an initial extension of range from eastern to western Greece. However, such changes in distribution could be hindered by the Pindos Mountains in Central Greece, which have peaks of up to approximately 2,600 m (although *Culicoides* species have occasionally been trapped at heights of 4 km). In addition, the model predicts that the risk of *C. imicola* occurring in the north-east of the country is lower, which is consistent with the field data from this area (33).

The Iberia-based model also predicts that Sardinia, Sicily and parts of southern Italy would be suitable for *C. imicola*. Recent field surveys have shown that *C. imicola* already occurs in Sardinia, Sicily and Calabria (M. Goffredo, personal communication) and further sampling could reveal the presence of the species over even greater areas of southern Italy.

The model also indicates that parts of the coastal regions of Albania, Yugoslavia, Bosnia and Croatia may be favourable for *C. imicola*. However, the presence of *C. imicola* in these areas is likely to be dependent on initial spread into either western Greece, from which location the species could migrate north, or eastern Italy, from which location adult midges could be blown across the Adriatic Sea (adult *Culicoides* can be carried by the wind for long distances) (49). However, even if *C. imicola* did reach these areas, permanent populations may fail to become established at some sites (e.g. Gjirokaster, Podgorica and Mostar) due to high rainfall (i.e. > 1,000 mm rain/year).

In Corsica, large numbers of *C. imicola* have recently been detected (October 2000) in the southern tip of the island and at one site on the central east coast (39). However, *C. imicola* was not found at trap sites in northern or western Corsica (39). The model predicts that the chances of *C. imicola* occurring at Ajaccio (Fig. 2, labelled site A) in the west of the island are small (although not impossible). Furthermore, it is unclear whether *C. imicola* can establish sustainable breeding populations in Corsica or whether the invasion of *C. imicola* from northern Sardinia (a distance of < 15 km) each summer is necessary to maintain the populations.

If the global mean temperature were to increase by 2°C by 2100 (as predicted by many climate change scenarios) (20),

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the range of *C. imicola* could be extended in Europe. For example, in Spain, the model indicates that the risk of *C. imicola* occurring further north and east is high. The range of *C. imicola* could even reach the south of France and parts of northern Italy. In Greece, the range of the species could potentially extend into the north-east of the country and continue a southwards migration. The risk of *C. imicola* occurring in European Turkey will also increase, and if *C. imicola* were to reach Albania, Yugoslavia, Bosnia or Croatia, greater areas of these countries would have favourable temperature conditions. Furthermore, given that the latest projections from the Intergovernmental Panel on Climate Change (published in July 2001) suggest that the global mean temperature could rise by up to 5.8°C by 2100 (21), it is possible that the range of *C. imicola* could expand into yet further areas of Europe. However, predictions of distribution under global warming based on climate data, which do not consider other determinants of distribution (e.g. interactions between species), may vary from actual distributions (14).

The predictions of the model for the potential distribution of *C. imicola* in Europe are based on climate data from 1931-1960 (1), due to the lack of essential temperature variables for some countries in the more recent 1961-1990 dataset (2). However, to investigate whether use of the 1961-1990 data would influence the model, the predicted values for the occurrence of *C. imicola* were compared for the two datasets at twenty-seven sites in Italy (for which all the necessary temperature variables are available in the 1961-1990 dataset). Using a paired *t*-test, no significant difference was found in the predicted values ($t = 0.18$, df [degrees of freedom] = 26, $P = 0.86$), strongly suggesting that the use of more recent climate data would have had no significant impact on the model. Examination of the climatic data for Italy revealed no significant change in the overall values used in the model between the two datasets.

In this paper, a simple model is presented for predicting the potential range of *C. imicola* in Europe, both currently and if conditions should warm as a result of global climate change. The model displayed a high degree of accuracy in predicting the occurrence of *C. imicola* in Iberia when compared with the published data (46) and also indicated that the distribution of *C. imicola* could potentially expand across most of southern Europe. *Culicoides imicola* is the principal vector species of BTV and AHSV in Europe, and hence the identification of areas which could provide favourable conditions for these insects provides a valuable insight into the areas at risk of these economically important disease-causing pathogens. In the future, models which predict the abundance of *C. imicola* should also be developed, as this will provide information about the level of risk experienced at sites where *C. imicola* occurs. To achieve this and to improve the accuracy of model predictions for Europe, more extensive field data on the presence and abundance of *C. imicola* are required. The information determined in this study can be used to target field surveys, and structured sampling in parts of the Mediterranean Basin is already underway.

Acknowledgements

Application des données climatologiques à la cartographie de la répartition potentielle de *Culicoides imicola* (Diptera : Ceratopogonidae) en Europe

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Résumé

Culicoides imicola, vecteur du virus de la fièvre catarrhale du mouton et du virus de la peste équine, est essentiellement présent en Afrique et en Asie, mais il a aussi été observé récemment dans certaines régions d'Europe. Un modèle de régression logistique, basé sur des données climatologiques (température, déficit de saturation, pluviométrie et altitude) et sur la répartition connue de *C. imicola* dans la péninsule ibérique, a été élaboré puis appliqué à d'autres pays européens, afin de dresser une carte de la propagation potentielle de *C. imicola*. Le modèle a identifié trois variables de température comme déterminantes pour

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la répartition de *C. imicola* dans la péninsule ibérique (minimum des températures minimales mensuelles, maximum des températures maximales mensuelles et nombre de mois de l'année avec une température moyenne inférieure ou égale à 12,5 °C). Le modèle indique que, dans des conditions normales, la répartition de *C. imicola* en Espagne, en Grèce et en Italie pourrait s'étendre et que le vecteur pourrait même gagner certaines régions d'Albanie, de Yougoslavie, de Bosnie et de Croatie. Pour simuler les effets du réchauffement de la planète, les valeurs de température retenues dans le modèle ont été augmentées de 2 °C. Dans ces conditions, la propagation de *C. imicola* en Europe pourrait être encore plus large.

Mots-clés

Arbovirus – Cartographie – Changements climatiques – Culicoides imicola – Fièvre catarrhale du mouton – Maladies transmises par un vecteur – Modèle – Peste équine – Réchauffement de la planète.

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Uso de datos climatológicos para cartografiar la distribución potencial de *Culicoides imicola* (Diptera: Ceratopogonidae) en Europa

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Resumen

Aunque el área de distribución de *Culicoides imicola*, vector de los virus de la lengua azul y la peste equina, se circunscribe esencialmente a Asia y África, también en partes de Europa se ha observado recientemente su presencia. En primer lugar se elaboró un modelo de regresión logística basado en datos climatológicos (temperatura, déficit de saturación, pluviosidad y altitud) y en la distribución descrita de *C. imicola* en la Península Ibérica. Después, para determinar los lugares en que *C. imicola* podría llegar a establecerse, se aplicó ese modelo a otros países de Europa. Del modelo se desprendía que los principales factores determinantes de la distribución de *C. imicola* en la Península Ibérica eran tres variables térmicas (la más baja de las temperaturas mínimas mensuales, la más alta de las máximas mensuales y el número de meses por año con temperatura media ≥ 12,5°C). La aplicación del modelo reveló que, en las condiciones actuales, la presencia de *C. imicola* en España, Grecia e Italia podría extenderse, y que el vector podría llegar a invadir partes de Albania, Yugoslavia, Bosnia y Croacia. Para simular los efectos del calentamiento planetario se incrementaron en 2°C los valores térmicos utilizados en el modelo. En tales condiciones, *C. imicola* podría propagarse incluso a otras partes de Europa.

Palabras clave

Arbovirus – Calentamiento planetario – Cambio climático – Cartografía – Culicoides imicola – Enfermedades transmitidas por vectores – Lengua azul – Modelo – Peste equina.

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